METHODS

Bat Activity Monitoring

Activity of bats at each site was monitored using Anabat detection systems before and after treatments occurred. Three monitoring stations were installed a random distance to the north of each herp array. Selected station locations were sometimes located in deep brush and dense stands of trees. At each station, we selected an orientation (1-360 degrees) for the bat detector such that microphones were not immediately obstructed by vegetation and could pick up the calls of bats flying by without interference. Monitoring station locations were recorded with GPS, and the same stations and detector orientations were reused each year. From night to night, bat activity depends on weather conditions, moon phase, insect activity, and other factors. To reduce variation in bat activity among sites due to these factors, the four sites in each block were monitored simultaneously. One block was monitored per night, and each block was monitored once per week, and the order of sampling each week was randomized. We monitored bat activity from June through August and attempted to achieve 12 nights of monitoring per site per season.

To monitor bat activity, ultrasonic detection systems (Anabats) were set up and activated just prior to dusk. Monitoring devices were positioned on posts such that they set 1 m above the ground. From 2001-2002, Anabats were angled at 45 degrees above the horizontal and were connected through Anabat ZCAIM units to laptop computers powered by portable batteries. Anabat ZCAIM units convert analog signals from the bat detector into digital signals to the computer. Because these systems were extremely prone to periodic failure, field crews monitored the systems throughout the night and bat calls were also recorded to a backup device (Sony minidisc recorders). From 2003-2005, we took advantage of new and more reliable technology that permitted storage of bat call data on compact flash cards. Thus, we replaced the ZCAIM/laptop recording systems with Compact Flash ZCAIMs. Since field crews no longer monitored the units at night, Anabats were also placed within PVC housings to protect the units from rain. To prevent rain from entering and damaging sensitive microphones, Anabats were oriented 45 degrees below the horizontal. Microphones were oriented to receive audio data reflected off flat, Lexan surfaces.

Call data were transferred from laptop computers nightly and from compact flash cards weekly. After data was transferred to an office computer, a technician examined each call file using Analook software. The technician kept all files that contained at least 2 bat calls (a sequence of > 1 echolocation pulses with < 1 s between sequential pulses). All other files containing 1 bat call or extraneous noise (insects, etc.) were discarded. Consistency in call file interpretation among technicians was achieved by thorough training and standardization of method. Bat activity was defined as the total minutes during which qualified calls were recorded during the official monitoring period each night. The official monitoring period started at 15 minutes past official sunset and continued for the next 4.5 hours.

Treatment effects on bat activity

To identify impacts of treatments on summer activity levels of bats, we compared relative changes in bat activity at control and treated sites. At the completion of field season 2005, we had two years of post-mechanical treatment data at most study sites. Using data from pre-treatment years (2001-2002) and post-treatment years (2004-2005), we calculated average minutes of activity per night for pre- and post-treatment periods at each monitoring station. We then used General Linear Model- Repeated Measured Analysis to compare pre- and post-treatment bat activity at treated and control sites. We also used linear regression to identify habitat structure variables that correlate with bat activity.

Herpetofaunal sampling

To sample reptiles and amphibians, we installed three drift fence arrays per site. Arrays were placed randomly within the site and at least 25m from the periphery. Each drift fence array consisted of three silt erosion fences with 2 pitfalls and 2 funnels per fence. Each fence was 6m long, started 7.5 m from a central point, and was positioned at an angle of 60 degrees from the other fences. The location of each trap site was recorded by GPS, marked with flagging, and revisited each year. Traps were open continuously from June to mid September each year, and arrays were checked for animals 3 days per week.

For each animal captured, we recorded species, snout-vent length, vent-to-tail length, mass, sex, and age. We uniquely marked lizards, but not amphibians or snakes. Hatchlings were also marked to evaluate reproductive success and survival probability before and after treatment.
To evaluate how herpetofaunal species responded to restoration treatments we first characterized bosque habitat in terms of its vegetation. Then we correlated herpetofaunal occurrence or relative abundance with these vegetation characteristics.

Vegetation changes at herp arrays

Using 15 variables from the 50 m ground cover transects and 4 m radius plots at each array (before and after treatment), we used a principal components analysis (PCA) to detect differences among arrays based on vegetation variables. Variables entered into the analysis included type and percent ground cover, percent overstory cover, number of dead branches and debris, number and size of native and non-native trees, and number of shrubs. To determine how restoration treatments altered bosque vegetation, we compared pre- and post-treatment factor scores using paired t-tests.

Lizard response to treatments

Most herpetofaunal captures were lizards (nearly 85% out of over 16,000 captures), and we examined the six most common lizard species. To evaluate how restoration treatments impacted lizards, we correlated species' occurrences and abundances with vegetation factor scores derived from the PCA. For three lizard species that were not ubiquitous throughout the study, we used a logistic regression analysis to determine which factor scores best predicted lizard species presence. We used a backward elimination procedure that eliminated variables with $P>0.25$ (Hosmer and Lemeshow 2000). To correlate relative species abundance with vegetation characteristics, we used a backward stepwise regression to identify significant vegetation factor scores. For the 3 species that were not ubiquitous at all our study sites, we conducted the regression analysis with data only from sites where the species occurred.

Amphibian response to treatments

Similar to analyses used to evaluate lizard species, we correlated amphibian species' presence and relative abundance with vegetation factor scores from the PCA. Two spadefoot toad species, Couch's Spadefoot toad (*Scaphiopus couchii*) and New Mexico spadefoot toad (*Spea multiplicata*) were combined to represent amphibians in the family Pelobatidae. Spadefoot toads were only present at 27 of 72 arrays (from before and after treatment), and therefore occurrence was analyzed using a logistic regression analysis. Three toad species, Woodhouse's toad (*Bufo woodhousii*), Great Plains toad (*B. cognatus*), and Red-spotted toad (*B. punctatus*) were combined to represent amphibians in the family Bufonidae. Toads were common throughout the study and therefore abundance was analyzed using a stepwise regression.

Amphibian response to flooding

In 2005, an unexpected experiment occurred when two of 12 study sites flooded for the first time during the Fuels Project. We noted duration and degree of flooding at these sites and compared post-flood capture rates of toads in 2005 with capture rates from previous years at these sites. Many toads were identified to genus only (*Bufo* spp.) because they were too small (<30mm) for individual species identification.

RESULTS

Treatment effects on bat activity

We had two seasons of pre-treatment (2001-2002) and post-treatment year (2004-2005) data for all monitoring stations except Middle 7. Because Middle 7 was introduced in 2002 to replace our unintentionally burned control site at Middle 4, we had only one season of pre-treatment data for monitoring stations at Middle 7. In pre-treatment years, we achieved fewer nights of monitoring than desired due to weather and equipment difficulties. Frequent night-time showers in 2001 and 2002 often necessitated that we bring in equipment prematurely, and thus several nights were not sampled successfully (for the full 4.5 hour period). In 2001, we achieved only 4-8 nights of sampling per station, and in 2002, we achieved 8-11 nights of sampling per station. However, drier weather and equipment improvements allowed us to successfully achieve 9-14 nights of sampling per summer in 2004-2005.

Results of GLM-Repeated Measures Analysis indicate overall bat activity was different between pre- and post-treatment years (i.e. significant time effect; Table 1). This time effect was not different between blocks (nonsignificant 'time*block' interaction). The significant interaction between time and assigned (control vs. treated site) indicates that bat activity was affected by invasive plant treatments. This interaction indicates that activity on treated sites increased to a greater degree in post-treatment years than activity on control sites (Figure 1). Thus, our analyses suggest that removal of exotic trees and woody fuels has had a positive effect on the use of sites by bats.

A significant block effect indicates that bat activity was different among North, Middle, and South blocks (Table 2). In pre- and post-treatment years, bat activity was higher on sites in the South block (Fig. 2). We used stepwise linear regression to determine if habitat structure variables from pre-treatment vegetation surveys (canopy cover, canopy height, midstory clutter, tree basal area, and exotic stem density) could explain the variation in bat activity among sites (pre-treatment years). Percent canopy cover was inversely related to bat activity among sites and explained 50.2% of the variation. Sites in South block had lower canopy cover values and higher levels of bat activity than North and Middle blocks. Lower levels of canopy cover likely reflect more open, less cluttered sites. This openness may improve the accessibility of the site to bat species with wider variety of flight styles. For example, more open sites may be more accessible to fast-flying species such as the Mexican free-tailed bat (*Tadarida brasiliensis*) whereas denser, more cluttered sites may only be accessible to more maneuverable species such as the Arizona myotis (*Myotis occultus*).

Table 1. Results of within-subjects contrasts of GLM-Repeated Measures Analysis comparing interactions between time period (pre- vs. post-treatment), block (North, Middle, South), and assigned (treated vs. control site).

Source	TIME	Type III Sum of Squares	df	Mean Square	F	Sig.
TIME	Linear	4049.306	1	4049.306	15.494	.000
TIME * BLOCK	Linear	732.009	2	366.004	1.400	.261
TIME * ASSIGNED	**Linear**	**1660.756**	**1**	**1660.756**	**6.355**	**.017**
Error(TIME)	Linear	8363.019	32	261.344		

Fig. 1. Minutes of bat activity per night on control and treated sites during pre-treatment (2001-2002) and post-treatment (2004-2005) periods.

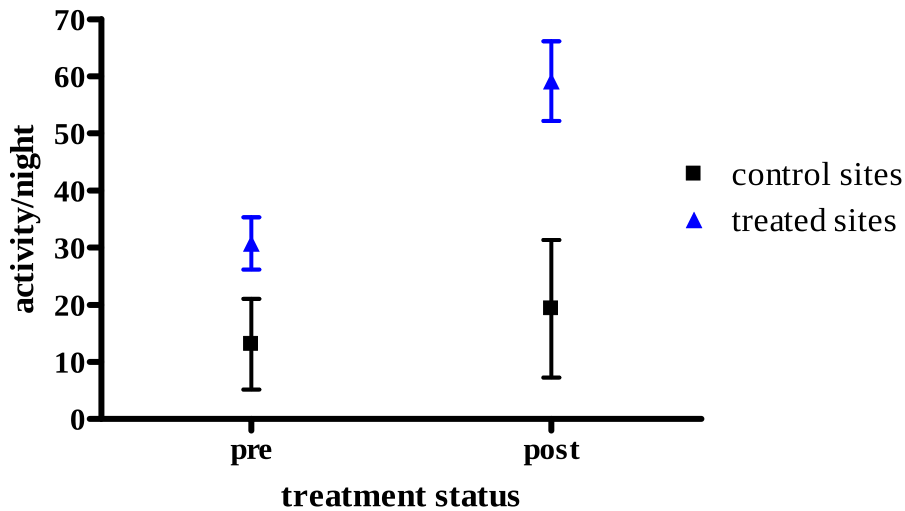


Table 2. Results of between-subjects tests from GLM-Repeated Measures Analysis comparing bat activity at control and treated sites during pre-treatment (2001-2002) and post-treatment (2004-2005) periods.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	50452.436	1	50452.436	31.226	.000
BLOCK	**28588.496**	**2**	**14294.248**	**8.847**	**.001**
ASSIGNED	11149.601	1	11149.601	6.901	.013
Error	51703.065	32	1615.721		

Fig. 2. Average minutes of bat activity per night for each study block during pre-treatment (2001-2002) and post-treatment (2004-2005) periods.

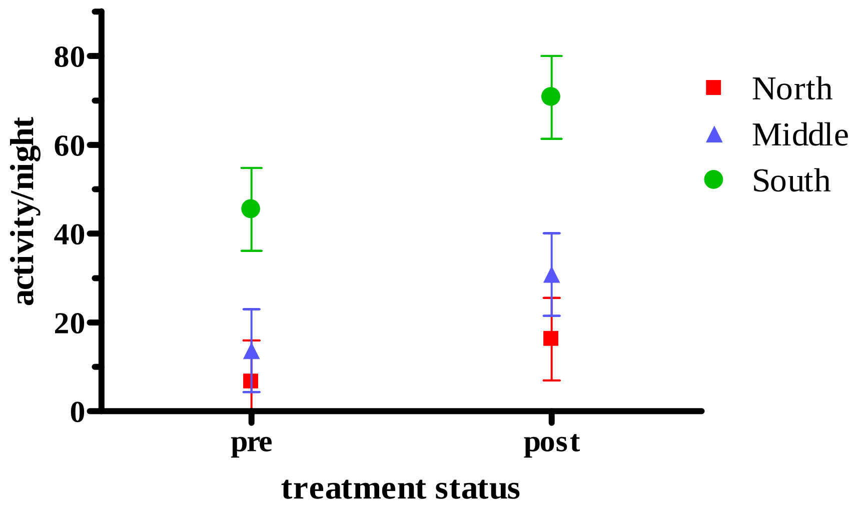


Table 3. Results of stepwise linear regression between habitat structure variables and average minutes of bat activity per night (for the pre-treatment period at all sites).

Model	Coefficient	Std. Error	t	Sig.
Constant	192.898	52.807	3.653	.004
Canopy Closure (%)	**-1.941**	**.611**	**-3.175**	**.010**

Herpetofaunal communities of the Middle Rio Grande Bosque

Historical Information on the Herpetofaunal Community

The Middle Rio Grande supports the most extensive, remaining gallery of cottonwood forest (*Populus deltoides wislizeni*) in the southwest (Hink and Ohmart 1984). This forest, or bosque, hosts a rich assemblage of vertebrates, particularly birds (Hink and Ohmart 1984). Several studies have focused on arthropod, bird, and mammal communities of the Middle Rio Grande bosque; however information on the herpetofaunal community is limited. A list of expected species may be assembled from recent studies, historic and museum records, and habitat associations from Degenhardt and others (1996). Because there are no studies of amphibians and reptiles in the bosque prior to channelization and damming of the river, it is difficult to characterize the herpetofaunal community of native, undisturbed cottonwood forest. More recently, Hink and Ohmart (1984) characterized herpetofauna associated with riparian vegetation of the Middle Rio Grande based on results of their pitfall surveys, museum records, and other field observations. Stuart and others (1995) reported herpetofauna captured at two sites within the Bosque del Apache National Wildlife Refuge (BDANWR) near Socorro, NM. Several studies have examined the lizard communities of desert riparian areas in Arizona. However, data from these studies are not comparable to Middle Rio Grande bosque because mesquite (*Prosopis velutina*) was the major overstory tree/shrub in the Arizona study areas, and cottonwood

(*Populus fremontii*) and willow (*Salix gooddingii*) had only a scattered or occasional presence (Vitt and others 1981; Jakle and Gatz 1985; Jones and Glinski 1985; Szaro and Belfit 1986).

Based on available literature, cottonwood forests and associated habitats of the Middle Rio Grande (including ditches, canals, ponds, sandbars, and drier peripheral riparian habitats) are used by at least 50 reptile and amphibian species. Species that were captured (Hink and Ohmart 1984; Stuart and others 1995) and species with other types of records in the Middle Rio Grande bosque (Hink and Ohmart 1984; Degenhardt and others 1996; Bailey and others 2001) are listed in table 1. The Eastern Fence Lizard (*Sceloporus undulatus*), New Mexico Whiptail (*Aspidoscelis neomexicana*, formerly genus *Cnemidophorus* from Reeder and others 2002), and Woodhouse's Toad (*Bufo woodhousii*) were frequently captured from Española to Socorro, NM (Hink and Ohmart 1984). Fifteen other species of lizards, snakes, amphibians, and turtles were captured infrequently, at a limited number of locations, or both (Hink and Ohmart 1984; Table 1). An additional 23 species of reptiles and amphibians were occasionally sighted or otherwise documented in the Middle Rio Grande Valley (Hink and Ohmart 1984; Table 1). In two mixed stands of mature cottonwood and saltcedar at BDANWR, Stuart and others (1995) detected 8 amphibian and reptile species (Table 1).

Most of the species captured are typically associated with upland habitats (for example, desert grasslands, shrublands, and arroyos) rather than mesic riparian forest (Degenhardt and others 1996). Hence, capture rates were highest in open vegetation types with sandy soils and sparse ground cover and lowest in stands with dense understories (Hink and Ohmart 1984). Species captured more frequently in open, sandy habitats with sparse vegetation (for example, open stands of intermediate aged cottonwoods) included Eastern Fence Lizards, New Mexico Whiptails, Chihuahuan Spotted Whiptails (*A. exsanguis*), Woodhouse's Toads, Great Plains Toads (*Bufo cognatus*), and Plains Spadefoots (*Spea bombifrons*; Hink and Ohmart 1984). However, Great Plains Skinks (*Eumeces obsoletus*) were captured frequently in stands with densely vegetated understories.

Species associated with wetter habitats within the bosque (for example, near permanent water) included Gartersnakes (*Thamnophis* spp.), Spiny Softshell Turtles (*Apalone spinifera*), Tiger Salamanders (*Ambystoma tigrinum*), Western Chorus Frogs (*Pseudacris triseriata*), and American Bullfrogs (*Rana catesbeiana*; Hink and Ohmart 1984). Although once abundant in the bosque, Northern Leopard Frogs (*Rana pipiens*) were rarely captured by Hink and Ohmart (1984) and are considered extirpated from Bernalillo, Socorro, and Sierra counties (Applegarth 1983; Bailey and others 2001). The absence or low numbers of these species captured likely reflect the loss of suitable wetland habitat along the river. From 1935 to 1989, surface area covered by wet meadows, marshes, and ponds declined by 73% along 250 miles of Middle Rio Grande floodplain (Roelle and Hagenbuck 1995).

Herpetofaunal Community of the Fuels Reduction Project

From 2000-2005, we documented 9 amphibian, 11 lizard, and 13 snake species. We captured 2,355 amphibians, and *Bufo woodhousii* (Woodhouse toad) was the most common. We captured 13,728 lizards (8,174 individuals). *Sceloporus undulatus* (Eastern fence lizard), *Aspidoscelis neomexicana* (New Mexico whiptail), and *A. exsanguis* (Chihuahuan spotted whiptail) were the most common lizards. We captured 152 snakes, and *Lampropeltis getula* (common kingsnake) was the most common. Few aquatic or moist habitat species are represented. We did not document several species that were listed in Table 1 (2 amphibian, 6 lizard, and 3 snake species), likely because we did not use the variety of sampling techniques employed in the other studies and we sampled only in mature cottonwood forest. Similar to previous studies, the majority of species we captured were upland species. For example, the New Mexico Whiptail is typically associated with open, sparse vegetation (Christiansen and others 1971).

Table 1. Species list of herpetofauna observed or captured in the Middle Rio Grande bosque and associated habitats (including ditches, canals, ponds, sandbars, and drier peripheral riparian habitat). Reference codes are as follows: HC = captures by Hink and Ohmart (1984), HM = museum records and other observations reported in Hink and Ohmart (1984) Appendix 2, D = habitat associations from Degenhardt and others (1996), B = Bailey and others (2001), S = captures by Stuart and others at BDANWR (1995).

Taxa	**Scientific Name**	**Common Name**	**REFERENCE**
Amphibians	*Ambystoma tigrinum*	Tiger Salamander	HC, D, B, S
	Bufo cognatus	Great Plains Toad	HC, D, B
	Bufo punctatus	Red-spotted Toad	HM
	Bufo woodhousii	Woodhouse's Toad	HC, D, B, S
	Pseudacris triseriata	Western Chorus Frog	HC, D, B
	Rana blairi	Plains Leopard Frog	B
	Rana catesbeiana	American Bullfrog	HC, D
	Rana pipiens	Northern Leopard Frog	HM, D, B
	Scaphiopus couchii	Couch's Spadefoot	HM, D, B
	Spea bombifrons	Plains Spadefoot	HC, B
	Spea multiplicata stagnalis	New Mexico Spadefoot	HM, D, B
Turtles	*Apalone spinifera*	Spiny Softshell Turtle	HC, D, B
	Chelydra serpentina serpentina	Eastern Snapping Turtle	D
	Chrysemys picta	Painted Turtle	HM, D, B
	Terrapene ornata	Ornate Box Turtle	HM, D, B
	Trachemys gaigeae gaigeae	Big Bend Slider	D, B
	Trachemys scripta elegans	Red-eared Slider	D
Lizards	*Aspidoscelis exsanguis*	Chihuahuan Spotted Whiptail	HC, D, S
	Aspidoscelis inornata	Little Striped Whiptail	HC, D, S
	Aspidoscelis neomexicana	New Mexico Whiptail	HC, D
	Aspidoscelis tesselata	Common Checkered Whiptail	HM, D
	Aspidoscelis tigris	Tiger Whiptail	HM
	Aspidoscelis uniparens	Desert Grassland Whiptail	HM, D, S
	Aspidoscelis velox	Plateau Striped Whiptail	HC
	Cophosaurus texanus	Greater Earless Lizard	D
	Crotaphytus collaris	Eastern Collared Lizard	D
	Eumeces obsoletus	Great Plains Skink	HC, D, B
	Holbrookia maculata	Common Lesser Earless Lizard	HC
	Phrynosoma hernandesi	Greater Short-horned Lizard	HM
	Phrynosoma modestum	Round-tailed Horned Lizard	HC, D

	Sceloporus magister	Desert Spiny Lizard	HM, D, B
	Sceloporus undulatus	Eastern Fence Lizard	HC, D, S
	Urosaurus ornatus	Ornate Tree Lizard	D
	Uta stansburiana	Common Side-blotched Lizard	HC, D
Snakes	*Arizona elegans*	Glossy Snake	HC
	Coluber constrictor	Eastern Racer	HM, D, B
	Crotalus atrox	Western Diamond-backed Rattlesnake	HM, B
	Crotalus viridis	Prairie Rattlesnake	HM, B
	Heterodon nasicus	Western Hog-nosed Snake	HM
	Lampropeltis getula	Common Kingsnake	HM, D, B, S
	Leptotyphlops dissectus	New Mexico Threadsnake	D, B
	Masticophis flagellum	Coachwhip	HM, B
	Pituophis catenifer	Gophersnake	HM, D, B
	Rhinocheilus lecontei	Long-nosed Snake	HM
	Sistrurus catenatus	Massasauga	HM
	Tantilla nigriceps	Plains Black-headed Snake	HM, B, S
	Thamnophis cyrtopsis	Black-necked Gartersnake	HM, D, B
	Thamnophis elegans	Terrestrial Gartersnake	D, B
	Thamnophis marcianus	Checkered Gartersnake	HM, D, B
	Thamnophis sirtalis	Common Gartersnake	HC, D, B

Table 2. Species list of herpetofauna captured in the Middle Rio Grande bosque (2000 to 2005), ordered within taxa by total number of captures.

Scientific name	Common name	2000	2001	2002	2003	2004	2005	Grand Total
Amphibians								
Bufo woodhousii	Woodhouse's Toad	89	190	293	45	136	472	1225
Bufo cognatus	Great Plains Toad	6	5	6	41	3	88	149
Scaphiopus couchii	Couch's Spadefoot	1	21	12	6	22	17	79
Spea multiplicata	New Mexico Spadefoot	1	9	1	2	7	5	25
Rana catesbiana	American Bullfrog		2					2
Spea bombifrons	Plains Spadefoot	2						2
Bufo punctatus	Red Spotted Toad						1	1
Pseudacris triseriata	Western Chorus Frog		1					1
Ambystoma tigrinum	Tiger Salamander		2				2	4
Turtles								
Trionyx spinifera	Spiny Softshell Turtle				1			1
Lizards								
Sceloporus undulatus	Eastern Fence Lizard	315	908	809	723	869	908	4532
Aspidoscelis neomexicanus	New Mexico Whiptail	227	843	681	818	583	455	3607
Aspidoscelis exsanguis	Chihuahuan Spotted Whiptail	263	846	428	496	514	551	3098
Aspidoscelis uniparens	Desert Grassland Whiptail	250	446	180	263	236	140	1515
Eumeces obsoletus	Great Plains Skink	45	147	91	114	156	174	727
Sceloporus magister	Desert Spiny Lizard		29	18	26	13	19	105
Uta stansburiana	Common Side-blotched Lizard	3	2	13	17	7	11	53
Aspidoscelis tigris	Tiger Whiptail	7	16	4	2	1	3	33
Aspidoscelis tesselatus	Common Checkered Whiptail		1	9	2	5	9	26

Aspidoscelis inornatus	Little Striped Whiptail			1			3	4
Phrynosoma cornutum	Texas Horned Lizard		1					1
Snakes								
Lampropeltis getula	Common Kingsnake	5	11	1	7	8	10	42
Pituophis catenifer	Gophersnake	1	5		9	5	10	30
Tantilla nigriceps	Plains Black-headed Snake	2	3		2	6	6	19
Thamnophis sirtalis	Common Gartersnake	2	5		1	3	4	15
Heterodon nasicus	Western Hog-nosed Snake	2	3	1	3	2	2	13
Crotalus viridis	Prairie Rattlesnake				1	6	1	8
Crotalus atrox	Western Diamond-backed Rattlesnake					1	5	6
Masticophis flagellum	Coachwhip		1	1	1	2		5
Thamnophis marcianus	Checkered Gartersnake		1		3			4
Arizona elegans	Glossy Snake				1	1		2
Leptotyphlops dulcis	New Mexico Threadsnake	1					1	2
Thamnophis elegans	Terrestrial Gartersnake	2						2
Rhinocheilus lecontei	Long-nosed Snake		1					1

Lizard response to restoration activities

Bosque vegetation

By conducting a PCA analysis of 15 vegetation variables (Table 1), we identified five factors that best explained the difference among arrays before and after treatment. Based on the correlation matrix (Table 2), sites with high Factor 1 scores have a more dense and woody environment, and sites with high Factor 2 scores have a more open understory.

Results from a paired-t test (table 3) showed that restoration treatments did alter the bosque vegetation. Before treatment, sites had a more dense and woody environment characterized by more non-native trees, dead branches, and little bare ground (Factor 1, table 2) compared to after treatment. After treatment, sites had a more open understory environment compared to before treatment. Factor scores were not significantly different in control sites before treatment compared to after treatment (table 3).

Correlating species presence or abundance with vegetation characteristics

Lizard species were correlated with factor scores associated with post-treatment conditions. Two species, Desert Grassland whiptail (*A. uniparens*) and Chihuahuan Spotted whiptail (*A. exsanguis*), were positively correlated with Factor 2 (tables 4 and 5). Four species, Great Plains skink (*Eumeces obsoletus*), Side-blotched lizard (*Uta stansburiana*), and Eastern Fence lizard (*Sceloporus undulatus*) were negatively correlated with Factor 1 (tables 4 and 5).

Table 1. Vegetation measured at each array before and after restoration treatments.

Variable	Method
percent bare ground	50 m transects
percent wood chips ground cover	50 m transects
percent forbs and grass ground cover	50 m transects
percent litter cover	50 m transects
depth of litter	50 m transects

percent woody debris ground cover	50 m transects
number of dead branches, sm diam.	4 m radius plots
number of dead branches, lg diam.	4 m radius plots
number of shrubs	4 m radius plots
number of exotic trees	4 m radius plots
average Cottonwood diameter	4 m radius plots
average Russian olive diameter	4 m radius plots
average saltcedar diameter	4 m radius plots
canopy cover	2 readings per array
basal area	1 reading with prism

Table 2. Correlation matrix for 2 of 5 factors resulting from PCA analysis of 15 vegetation variables around herp arrays. Major variables that influence factor scores are in bold.

Vegetation variables	Factor 1	Factor 2
% bare ground	**-0.562**	-0.108
% wood chips	-0.348	0.268
% forbs and grass	-0.451	-0.041
% litter cover	**0.718**	-0.337
% litter depth	0.290	0.202
% woody debris ground coverage	0.494	**0.725**
No. dead branches, sm diam.	**0.700**	0.243
No. dead branches, lg diam.	**0.638**	0.484
shrub count	-0.301	0.104
exotic trees	0.477	**-0.648**
Cottonwood diameter	0.093	-0.328
Russian olive diameter	0.449	-0.334
saltcedar diameter	**0.561**	-0.432
canopy cover	0.366	-0.072
basal area	0.408	0.219

Table 3. Results of paired t-tests comparing vegetation factor scores at arrays before and after treatment.

	treated sites (n=27)				control sites (n=9)			
	mean (pre)	mean (post)	*t*	P	mean (pre)	mean (post)	*t*	P
Factor 1	0.383	-0.504	7.23	**<0.001***	0.230	0.130	0.24	0.819
Factor 2	-0.510	0.650	-4.47	**0.001***	-0.396	-0.027	-2.08	0.071
Factor 3	-0.074	0.094	-0.74	0.468	0.004	-0.063	0.23	0.825
Factor 4	0.294	-0.270	2.08	**0.048***	-0.130	0.064	-0.55	0.599
Factor 5	-0.265	-0.226	-0.21	0.838	0.802	0.667	0.233	0.822

Table 4. Results of logistic regressions predicting the presence of lizard species from vegetation factor scores. Classification accuracies of models are in parentheses.

Species	Pos. or Neg. Correlation	Vegetation factor	Factor description	P value
Desert Grassland whiptail	+	Factor 2	open understory	P<0.001
	-	Factor 3	mature	(73.6%)
Side-blotched lizard	-	Factor 1	dense & woody	P<0.001
	+	Factor 5	litter cover	(90.3%)
Eastern Fence lizard	-	Factor 1	dense & woody	P=0.001
(*Sceloporus undulatus)*				(75.0%)

Table 5. Results of linear regression predicting lizard species abundance from vegetation factor scores.

Species	Pos. or Neg. Correlation	Vegetation factor	Factor description	P value R squared value
Desert Grassland whiptail		model not significant		
New Mexico whiptail		model not significant		
Chihuahuan Spotted whiptail	+	Factor 2	open understory	P=0.001, R-sq.=0.176
Great Plains skink	-	Factor 1	dense & woody	P=0.009, R-sq.=0.127
	+	Factor 3	mature	
Side-blotched lizard	-	Factor 1	dense & woody	P=0.021. R-sq.=0.462
Eastern Fence lizard	-	Factor 1	dense & woody	P<0.001, R-sq=0.339
	+	Factor 3	mature	
	+	Factor 4	plant cover	

Amphibian response to treatments

Spadefoot toads (Family Pelobatidae) were predicted to be absent at sites with high Factor 1 scores (dense, woody environments) and to be present at sites with higher Factor 4 scores (more plant ground cover; Table 6). Relative abundances of spadefoot toads and true toads (Family Bufonidae) were negatively correlated with sites with high Factor 1 scores (dense, woody environments; Table 7).

Table 6. Results of logistic regression predicting the presence of spadefoot toads from vegetation factor scores. Classification accuracy is in parenthesis.

Correlation	Vegetation factor		P value
-	Factor 1	dense, woody	P=0.002
-	Factor 3	mature	(66.7%)
+	Factor 4	plant ground cvr	

Table 7. Results of regressions correlating relative abundance of spadefoot toads and true toads with vegetation factor scores.

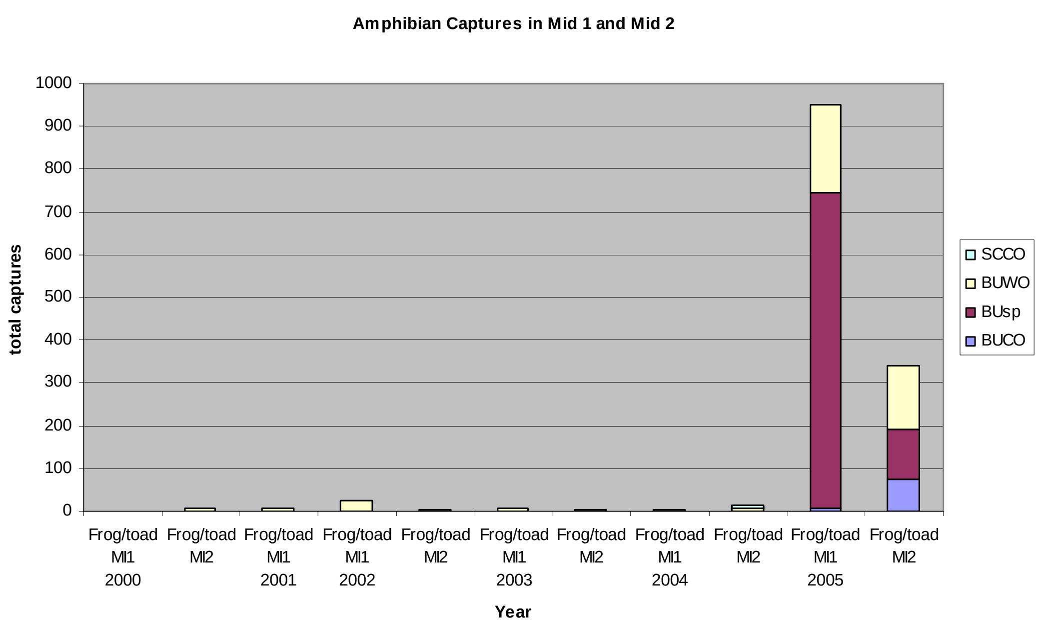
Family	Correlation	Vegetation factor		P value
Spadefoot toads	-	Factor 1	dense, woody	P=0.010, R-sq. = 0.228
True toads	-	Factor 1	dense, woody	P=0.005, R-sq. = 0.108

Amphibian response to flooding

Middle 1 and Middle 2 are north and south, respectively, of the city of Los Lunas in Valencia County. In 2005, flooding of these sites was a consequence of heavy winter snowpack (record-breaking levels) being melted by high spring temperatures. This runoff swelled local reservoirs to capacity and increased the amount of in stream flow during May. These 2 study sites likely began to flood in early April. Sites were sufficiently dry to open herp arrays by the fourth week of June. Middle 1 experienced higher water levels than Middle 2. We observed Middle 1 to be one to three feet underwater, with water in the riparian area continuous with water in the main channel of the Rio Grande. We observed a current moving downstream through the cottonwood stand. Middle 2, however, was flooded by rising ground water instead of overbank flow. We observed standing water and saturated soils in Middle 2. High water tables were evident; groundwater would flow into buckets as we bailed water from our belowground pitfall traps.

After this flood event in 2005, we captured more toads at these two sites (Middle 1 and Middle 2) than toad captures from all previous years and sites combined (Figure 3). Temporary pools in these sites contained eggs and tadpoles of *Bufo cognatus* and *B. woodhousei*. The day following some heavy rains, we captured over 500 toads (*Bufo* spp.) in traps at these 2 sites. Metamorphs made up the majority of captures. These toadlets were approximately 25 mm (snout-vent length).

Figure 3. Total number of toad captures in study sites Middle 1 and 2 from 2000 to 2005. These sites flooded during the spring of 2005.



SUMMARY

Due to significant interannual and interblock variation in capture rates and variation in the timing of treatments among sites, pre- vs. post-treatment comparisons of the herpetofaunal community are not easily performed. By investigating species' correlations with habitat variables, we can infer the effects of restoration treatments on herpetofaunal populations. Overall, five of the six most common lizard species and both amphibian groups occurred in or were more abundant in sites with post-treatment vegetation characteristics. Therefore, restoration treatments appear to alter the habitat in a way that would allow lizard species to persist or to be abundant.

There are also species-specific responses to restoration activities. For example, both Great Plains skinks and Side-blotched lizards were negatively correlated with dense, woody environments, but skinks were positively correlated with sites with a more mature cottonwood environment whereas Side-blotched lizards were positively correlated with sites with more plant ground cover (grass and herb).

None of the lizard species in New Mexico are true riparian species, nor are they strongly dependent on aquatic or wet habitats typically found in riparian systems. For example, the New Mexico Whiptail is typically associated with open, sparse vegetation (Christiansen et al. 1971). Chihuahuan Spotted whiptails, while associated with mesic habitats, are typically found in pinyon-juniper woodland and grassland habitat (Degenhardt et al. 1996). Not surprisingly, these species increase when habitats are modified to reduce woody ground cover and create a more open understory (i.e. conditions resembling upland habitats). Riparian areas typically have much higher plant and animal diversity compared to upland habitats (Stevens et al. 1977; Farley et al. 1994; Maisonneuve and Rioux 2001), and upland lizard species may be drawn to riparian areas due to their abundant food supplies.

Future analyses will allow us to explore the mechanisms explaining changes in lizard species abundance. By evaluating the proportion of adults and hatchlings in experimental sites compared to control sites before and after treatments, we will determine if lizard abundance is increasing due to increased reproductive effort. If reproductive effort has not changed, then perhaps lizards are moving into restored habitats through immigration.

All amphibian species found in the bosque require either temporary or permanent water sources to lay eggs and for tadpole development (Degenhardt et al. 1994). Therefore mechanisms explaining amphibian responses are likely to be different than those explaining lizard responses. As seen from captures in summer 2005, flooded sites had nearly 45 times as many toads as seen in any other season since the project began in 2000. Although amphibian habitat associations showed that true toads and spadefoot toads were negatively correlated with habitat features found in pre-treatment sites, it seems that for *Bufo* species, they respond much greater to the presences of temporary pools. Therefore changes in amphibian abundance may be due to factors other than restoration activity.

Overall, restoration treatments appear to be a beneficial or at least, nondamaging, to the existing herpetofauna of the Middle Rio Grande bosque. However, amphibian species would benefit from land managers incorporating spring flood events as part of their restoration efforts.

Literature Cited

Applegarth, J. S. 1983. Status of the leopard frog (Rana pipiens) and the painted turtle (Chrysemys picta) in the Rio Grande of north-central NM. Research report, Corps of Engineers, Albuquerque District, 78 p.

Bailey, James A.; Propst, David L.; Painter; Charles W.; Schmitt, C. Gregory; Willimas, Sartor O., III. 2001. Status of native wildlife in the Middle Rio Grande Valley of New Mexico. The New Mexico Journal of Science 41(1): 30-40.

Christiansen, James L.; Degenhardt, William G.; White, James E. 1971. Habitat preferences of *Cnemidophorus inornatus* and *C. neomexicanus* with reference to conditions contributing to their hybridization. Copeia 2: 357-359.

Degenhardt, William G.; Painter, Charles W.; Price, Andrew H. 1996. Amphibians and reptiles of New Mexico. University of New Mexico Press. 430 p.

Farley, G. H.; Ellis, L. M.; Stuart, J. N.; Scott, N. J. 1994. Avian species richness in different-aged stands of riparian forest along the Middle Rio Grande, New Mexico. Conservation Biology 8: 1098-1108.

Hink, Valerie C.; Ohmart, Robert D. 1984. Middle Rio Grande biological survey. Final Report to the U.S. Army Corps of Engineers Contract No. DACW47-81-C-0015. Center for Environmental Studies, Arizona State University. 193 p.

Hosmer, David and Stanley Lemeshow. 2000. Applied logistic regression. 2nd edition. Wiley Publishing. 373 p.

Jakle, M. D.; Gatz, T. A. 1985. Herpetofaunal use of four habitats in the Middle Gila River drainage, Arizona. In: Johnson, R.R.; Ziebell, C. D.; Patton, D. R.; Ffolliott, P. F.; Hamre, R. H. Eds. Riparian ecosystems and their management: reconciling conflicting uses. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-120: 355-358.

Jones, K. B.; Glinski, P. C. 1985. Microhabitats of lizards in a southwestern riparian community. In: Johnson, R.R.; Ziebell, C.D.; Patton, D.R.; Ffolliott, P.F.; Hamre, R.H. Eds. Riparian ecosystems and their management: reconciling conflicting uses. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-120: 342-346.

Maisonneuve, C, and S. Rioux. 2001. Importance of riparian habitats for small mammal and herpetofaunal communities in agricultural landscapes of southern Quebec. Agriculture ecosystems and environment. v.83, no.1-2, SI, p.165-175

Reeder, T. W.; Cole, C. J.; Dessauer, H. C. 2002. Phylogenetic relationships of whiptail Lizards of the genus Cnemidophorus (Squamata : Teiidae): A test of monophyly, reevaluation of karyotypic evolution, and review of hybrid origins. American Museum Novitates 3365: 1-61.

Roelle, J. E.; Hagenbuck, W. W. 1995. Surface cover changes in the Rio Grande floodplain, 1935-1989. In: LaRoe, E.T.; Farris, G.S.; Puckett, C.E.; Doran, P.D.; Mac, M.J. Eds. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service: 290-292.

Stevens, L. E., B. R. Brown, J. M. Simpson, and R. R. Johnson. 1977, The importance of riparian habitat to migrating birds, p. 156–164: In: R. R. Johnson and D. A. Jones (tech. coord.), Importance of preservation and management of riparian habitats: a symposium. U.S. For. Serv. Gen. Tech. Rep. RM-43.

Stuart, J. N.; Farley, G. H.; Valdez, E. W.; Bogan, M. A. 1995. Studies of vertebrates in selected riparian and aquatic habitats on Bosque del Apache National Wildlife Refuge, New Mexico. U.S. Fish and Wildlife Service, Albuquerque, NM.

Szaro, R. C.; Belfit, S. C. 1986. Herpetofaunal use of a desert riparian island and its adjacent scrub habitat. Journal of Wildlife Management 50: 752-761.

Vitt, L. J.; Van Loben Sels, R. C.; Ohmart, R. D. 1981. Ecological relationships among arboreal desert lizards. Ecology 62: 398-41.